HALMSTAD UNIVERSITY

Master's Programme in Renewable Energy Systems

MASTER THESIS

Heat storages in Swedish district heating systems

An analysis of the installed thermal energy storage capacity

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Abstract

District heating is the most common source of heating in Sweden and has played a crucial part in the country's substantial reductions of carbon dioxide emissions. This recycling technology is ideal in order to use thermal energy as efficiently as possible and makes the goals set for a sustainable future more achievable. The future potential of this technology is therefore huge. Today, a lot of the district heating systems have installed heat storages in order to improve the systems reliability and performance. These heat storages have the potential to be utilized even further in the future by acting as a balancing power for the power grid. However, there is currently no data available regarding the storage capacity available in the district heating systems. This thesis therefore seeks to quantify the installed storage capacity in Swedish district heating systems. The data gathered regarding this can then be utilized in research regarding potential future applications of heat storages, such as balancing the power grid. All collected data regarding heat storage capacity has also been analyzed in an effort to find any correlations between the relative storage capacity and the size, energy sources, customer prices and operational costs of each investigated system. This analysis has concluded that most of the district heating systems in Sweden have installed storage capacity and that it is more commonly used in larger systems. It is also concluded that most of the installed storage capacity is used to counteract daily heat load variations. The heat storages influence district heating systems by reducing their operational costs as well.

Keywords

District heating *Sustainable* *Heat storage* *Quantification*

Sammanfattning

Den vanligaste formen av uppvärmning i Sverige är fjärrvärme. Sverige har minskat landets utsläpp av koldioxid kraftigt det senaste årtiondet och fjärrvärmen har bidragit stort till denna bedrift. Denna teknologi är ideal när det gäller att återvinna samt använda värme så effektivt som möjligt. Potentialen för den teknik i framtiden är därför stor. Många fjärrvärmesystem har idag värmelager i systemet för att öka dess effektivitet och pålitlighet. Dessa värmelager kan potentiellt utnyttjas ännu mer i framtiden genom att aggera som balanskraft för elnätet. Det finns dock ingen data tillgänglig gällande lagerkapaciteten som finns tillgänglig i fjärrvärmesystemen i dagsläget. Syftet med detta examensarbete är därför att kvantifiera och analysera den installerade lagerkapaciteten i Sveriges fjärrvärmesystem. Den insamlade datan kan sedan användas i studier för framtida applikationer för värmelager, så som att agera som balanskraft för elnätet. All insamlad informationen om värmelagernas kapacitet har även analyserats för att hitta samband mellan den relativa lagerkapaciteten för varje fjärrvärmesystem och dess storlek, energikällor, kundpriser samt driftkostnader. Slutsatser som har dragits från denna analys är att de flesta fjärrvämesystemen i Sverige har värmelager installerade, samt att värmelager är vanligare i större fjärrvärmesystem. De flesta värmelagren används till att balansera daliga variationer i värmelasten och värmelager sänker även driftkostnaderna för fjärrvärmesystemen.

FOREWORD

This thesis is written as a part of the course *Dissertation in Energy Engineering*, which is represents 15 credits of the *Master's Programme in Renewable Energy Systems* in Halmstad University. The thesis has been written during the spring term of 2016, opposition and presentation of the thesis has also been performed during this period.

Sven Werner has been my supervisor for this thesis, and it would not have been possible to complete the thesis without his advices. I would therefore like to extend my gratitude to him for all his help. I would also like to thank all the companies who have been helpful and responded to my questions. Without their responses regarding heat storages in their systems, this thesis would have not data to draw its conclusions from. Thus, a big thank you to all who helped make this happen.

Halmstad the 30th of May 2016

Robin Eriksson

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1 INTRODUCTION

This chapter describes the background of why this thesis is written, and explains the purpose behind the thesis. It also contains a summary of the method used to perform the analysis.

1.1 Background

The most common source of heating in Sweden is district heating. It heats more than half of all the households and premises in the country, and over 90% of all apartment blocks use this method of heating. As implied by the name, district heating comes from somewhere within the district. District heating is supplied by a central plant, as opposed to every house having its own boiler. This enables the system to utilize advanced methods which allow it to run on many different fuels as well as recycle heat that would otherwise go to waste, which is beneficial to both the household and the environment. It is said that the district heating plant is the heart spreading warmth throughout the district.

Sweden has made substantial reductions in its emissions of carbon dioxide in the last decade. District heating is the secret behind this accomplishment. City-wide district heating networks can utilize surplus heat from industrial plants, waste incineration or thermal power generation. In these networks it is also possible to make use of low carbon fuels such as biomass, geothermal and solar energy.

There is a trade organization in Sweden for companies which generate district heating. It is called the Swedish District Heating Association (Svensk Fjärrvärme) and because of this association, a lot of statistics regarding district heating is publicly available. The association has more than 130 member companies all over Sweden, and the members are responsible for 98% of the district heating supplied throughout the country. An example of the kind of statistics that is available is depicted in the diagram below. It shows the national distribution of the different type of customer’s in Swedish district heating systems.

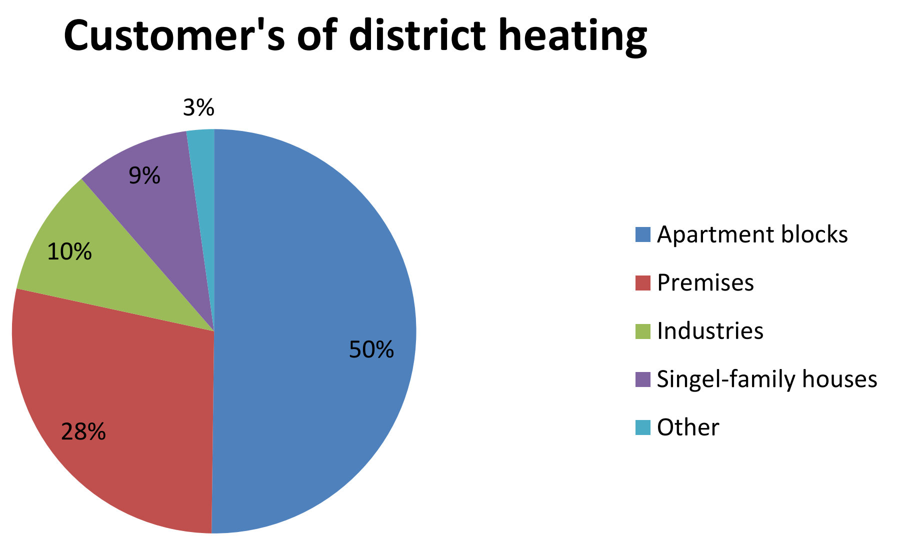

Diagram 1 - Distribution of customer’s in Swedish district heating systems. Source: Swedish District Heating Association.

There is a lot more statistical data available than the example above, however there is currently no data available regarding thermal energy storages in these systems. Since there are a lot of advantages to having thermal energy storage in the system, such data could prove very useful in future planning of district heating. Data regarding the current storage capacity could prove very useful when investigating the future potentials of district heating, such as seasonal heat storages or using the heat storages for balancing the power system.

Accumulators are a common type of thermal energy storages that is used in district heating, and installing one can improve the efficiency and profitability of the system. Data for the existing accumulators, and other types of heat storages that may exist in district heating systems, can therefore help identify when it is profitable to install heat storage in a district heating system. This can be achieved by comparing different performance indicators for the systems without any storage capacity with the systems that has installed heat storage capacity. (Svensk Fjärrvärme, 2016)

1.2 Purpose

This thesis aims to quantify the current capacity of heat storages in Swedish district heating systems. By doing so it also intends to analyze the distribution of the heat storages according to the corresponding systems sizes, energy sources, operational costs and customer prices of the systems. The following scientific questions will form the basis of this analysis:

- Does the installed storage capacity vary with the size of the system?
- How does the installed storage capacity vary with different energy sources?
- Does high storage capacity enable more competitive pricing of district heating?
- Does the installed storage capacity influence the operational costs of a district heating system?

These four questions will provide performance indicators which will allow evaluation of the impact heat storages have on district heating systems. Since no information about heat storages in Swedish district heating systems is available today, this will also provide useful information for potential future uses of the heat storages.

1.3 Delimitations

This analysis focuses on Swedish district heating systems and it only investigates the largest systems. There are over 400 district heating systems in Sweden, but only 167 of them have been analyzed due to the amount of time and effort that would be required in order to analyze them all. The analyzed systems do however represent 97% of all heat sales in Swedish district heating systems during 2014. No cold storages used for district cooling are included in this analysis. Some of the included heat storages are not yet installed in the systems, but planned for the near future. These heat storages are found in the systems located in Nybro, Ystad and Vänersborg. All analyzed systems are listed in *Appendix B*.

The statistical data for energy sources, system sizes, annual revenues and operational costs used in this analysis have been obtained from both the Swedish District Heating Association and the Swedish Energy Market Inspectorate (Energimarknadsinspektionen). This data does not always conform completely, which may be reflected in the results.

1.4 Method

Collecting statistical data regarding heat storages in Swedish district heating systems is the main focus of this thesis. This data is also used to analyse the distribution of the heat storages and the benefits they currently offer to their systems.

All data regarding heat storages have been collected through websites or by contacting the different district heating companies directly. See *Appendix A* for the companies that have been contacted by e-mail or phone. The websites used to gather this information are either the district heating companies own websites, or news articles regarding the companies and their heat storages. The collected data was compiled in an Excel-file where it was cross-referenced with statistical data for the systems annual heat sales, annual operational costs, annual revenues and the systems distribution of energy sources used for heat generation. This statistical data was acquired from both the Swedish District Heating Association and the Swedish Energy Market Inspectorate.

Key figures for systems with installed storage capacity and systems without storage capacity were obtained using this data. The figures of systems with storage capacity were then compared to the figures of systems without storage capacity in order to determine the impact heat storages have on district heating systems. Diagrams were also produced in order to see if any correlations could be found between the systems relative storage capacity and their average annual revenues, average annual operational costs, annual heat sales and the energy sources used by the systems. The results of this were then analysed and discussed in order to motivate any conclusions that can be drawn from this.

2 FRAME OF REFERENCE

This chapter presents the theoretical reference frame that this analysis is based upon. It is a summary of the existing knowledge and previously performed research on the relevant subjects.

2.1 District heating systems

The fundamental idea behind district heating is to use local fuel or heat resources that would otherwise be wasted. A heat distribution network of pipes is used as local market place in order to satisfy local heating demands. Demands from the heat market, a cheap suitable heat source, as well as pipes that connect the heat demands with the heat source are all required in order to make the idea of district heating systems competitive. These three elements must be available locally, because the use of short pipes will keep the capital investment to a minimum. There are a lot of synergies resulting from connecting local demands with the available local heat sources, which is the main driving force for district heating. Space heating and preparation of domestic hot water are both suitable heating demands. District heating is also suitable for low temperature industrial heating demands.

As stated by Werner and Frederiksen in their book *District Heating and Cooling*, “The five current, suitable, strategic local heat and fuel resources for district heating systems include:

- Usable upgraded excess heat from thermal power stations. This method is called *combined heat and power* (CHP) or cogeneration.
- Usable heat obtained from waste incineration. This method is used in *Waste-to-Energy* plants.
- Usable *excess heat from industrial processes* and fuel refineries.
- Fuels that are difficult and bulky to handle and manage in small boilers, including most *combustible renewables*, such as wood waste, straw, or olive residues.
- Natural *geothermal heat sources*.” (Werner & Frederiksen, 2013)

The required capital investments in the distribution network and the heat generation plants necessary for peak and backup generation is high. Therefor the strategic heat sources must have a low cost in order to compensate for this. Plants used for peak and backup heat supplies are needed to be able to meet customer heating demands during times of extreme cold, or when the normal heat resources are temporarily unavailable.

The aggregate heat demand of the customers determines the heat loads that the district heating system needs to meet; here space heating is the dominant factor in heat demand for district heating. Creating a comfortable indoor climate, when the outdoor temperature is lower than what is desired indoors, is the goal of space heating. The heat demand for space heating increases the colder the local climate is. This is because the space heat supply should compensate for heat transmission losses, as well as heating the air supply in ventilation systems.

The heat transmission consists of the leakage of heat from the indoor areas through walls, roofs and windows in the form of heat radiation and heat conduction. The transmission losses will also be higher the colder the local climate is. Lowering the flow of heat is possible by placing insulation in wall cavities and using multiple panes of glass in windows. The difference in temperatures between outdoors and indoors, the heat transmission resistance and the total surface area between the outdoor and indoor environments are what determine the heat power required in order to maintain the indoor temperature.

Heat load is the heat power which represents the heat supply that is needed in order to satisfy the customer's heat demand. The heat load should be equal to the customer's heat demand over a longer period of time. When the heat load is smaller than the heat demand, the condition of delivery will not be fulfilled. It is possible to store heat in the distribution network on a short-term basis when the heat load is greater than the heat demand. This difference between heat load and heat demand can also be stored for later use by using heat storage units in the system.

Heat load varies over time and these variations are usually categorized as either seasonal heat load variations or daily heat load variations. Seasonal heat load variations are the result of the fact that winter days are colder than summer days, which leads to a concentration of the space heating supply during the period extending from early autumn to late spring. Daily heat load variations originate mainly in weather fluctuations, and also in normal human behaviour. The use of hot water is an example of behaviours that increase heat loads during daytime in comparison to those of nights. (Werner & Frederiksen, 2013)

2.2 Thermal energy storages

Heat or cold can be stored using thermal energy storage systems. The main use of thermal energy storage is to overcome the mismatch between the use of energy and the conversion of it. A thermal energy storage system consists of three steps: charge, storage and discharge. When charging, energy is supplied to a storage system where it is stored until a later time. The storage is then discharged when a heat demand needs to be met. Benefits that can be obtained when implementing heat storage in an energy system consists of:

- Better system reliability and performance.
- Reduced capital and operational costs.
- More efficient use of energy.
- Reduced pollution of the environment.

Sensible heat storage occurs whenever energy is stored, increasing or decreasing the temperature of a storage material. The storage material can be water, oil, air, concrete, bedrock, brick, etc. The storage material is usually selected according to the heat capacity of the material and the amount of space available for storage. Heat storages in district heating systems use water as storage material, since water is already circulating in the system.

The relative sizes of installed heat storages determine what type of load variation they can manage. In the review article *Thermal energy storage systems for district heating and cooling* by Sven Werner and Henrik Gadd, they estimated reference levels for relative storage capacity needed in order to manage the daily and seasonal load variations of the district heating systems included in their analysis. In order to counteract the seasonal variation a relative storage capacity of 1430 m^3/TJ was needed, and a relative storage capacity of 2.5 m^3/TJ was needed to counteract the daily load variations. It is also worth noting that most of the systems analyzed in this review article tend to utilize their heat storages in order to counteract daily heat load variations.

Large water tanks are the most common storage technology used in order to manage daily heat load variations in district heating systems. Another common operation strategy is to increase the supply temperature shortly before expected peaks in the aggregated heat load. This is a very short-term operation strategy for storing heat in the distribution network itself, which is suitable for hourly heat load variations. The water turnover in a district heating system is around 1-2 hours depending on the system size, thus the timescale for this heat storage is very short. When the new supply temperature reaches the flow control in each substation, the local storage effect will disappear.

Investments for storage installations in district heating will lead to various situations which generate cash flows. These following cash flow situations are mentioned in the review article *Thermal energy storage systems for district heating and cooling* by Gadd and Werner:

CHP plants generate both electricity and heat. It is possible to make the stiff generation connection between power and heat generation more flexible with heat storage capacity. By concentrating the plant operation at part loads during day-times, higher electricity revenues can be achieved. The heat storage will then be charged during the day and discharged during the night.

When a biomass boiler is exposed to frequent load changes it can result in lower seasonal conversion efficiency. The boiler load can be kept more constant by installing heat storage capacity. Because of the lower system loads, the heat storage will be charged during the night. Then during the day when the system loads are high, the heat storage will be discharged. This will maintain higher boiler conversion efficiency.

Strong variations in the heat recovery of various industrial processes can be reduced if heat storage capacity is installed before the heat supply to the distribution network. This will make recovery of surplus heat from industrial processes easier to implement. When the process is running the heat storage will be charged, and then discharged when the process no longer generates excess heat.

The demand for expensive peak loads can be reduced by storing heat. When the system loads are higher, during the night, the heat storage will charge and then discharge when the loads are higher again, during the day. If the heat storage is used actively during system load peaks it will also reduce the demand for peak load capacity. The avoided investment cost in peak load capacity is then the cost benefit of installing heat storage capacity.

Tanks used for thermal storage can also act as pressurization tanks. A pressurized tank or an atmospheric storage tank located at the highest system altitude can accomplish static pressurization. The avoided investment in alternative a pressurisation system without storage capacity represents the cost benefit. In case of a major water leakage in the distribution system, the tank used for thermal storage can be utilized as water storage until the leak is rectified.

The more of the cash flow situations mentioned above that a heat storage utilize during a year, the more profitable it becomes. The product of the number of times each cash flow situation appears during a year becomes the total annual cash flow. Because of this it is easier for a heat storage solving many daily load variations to reach acceptable profitability than it is for a heat storage that is only solving one seasonal load variation. (Cabeza, 2015) (Werner & Gadd, 2015)

2.3 Future potential of heat storages

The future potential of heat storages in district heating systems is huge and there are two future trends that can be expected regarding this. These trends are seasonal heat storages and heat storage for balancing the power system.

The variable cost of the base load plants is rather low in the current district heating systems, while the peak load plants are much more expansive to operate. This is because they use fossil fuels, which is associated with high carbon or energy taxes here in Sweden. Hence, there is an incentive for reduced peak capacity and less use of expansive peak fuels in the future. Large pit heat storages can be used in order to achieve this. It is possible to install heat storages with the capacity of storing millions of cubic meters, and with this the whole seasonal load variation can be eliminated in medium sized systems.

As the power generation is shifted more and more towards renewable energy sources, such as wind and solar, higher proportions of the power generation will be variable in the future. In order to counteract this expanding future problem, it is possible for district heating systems to provide balancing power with their heat storages. A combination of CHP-plants, large scale electric boilers and heat pumps can be used to generate this balancing power. During generation shortages the CHP-plants can supply electricity, and during generation surpluses the boilers and heat pumps can absorb electricity to charge the heat storages.

With higher interaction between the power system and the district heating system it is possible to add a higher proportion of wind energy to the power system. This is because the associated wind power peaks can be absorbed in the district heating system by heat pumps and electric boilers. (Werner & Gadd, 2015)

3 THE ANALYSIS

In this chapter the working process of the analysis is described in detail. The sources of all statistical data, as well as the method used for data gathering are also revealed in this chapter.

3.1 Existing heat storages

In order to locate as many heat storages as possible it was first necessary to identify all the district heating systems in Sweden. This was done through statistical data from the Swedish district heating association, and according to the data there are currently over 400 district heating systems in Sweden. The data also contains information regarding the annual heat sales for each system as well as what energy sources that has been used in order to generate heat for each system. Data that is relevant for 2014 was downloaded and a list was created using this data, where all of the systems are sorted according to their respective size. The companies were prioritized according to the size of their systems and the Internet was then searched for information regarding heat storages in these systems. Firstly the websites of each company was checked for information about the subject. If nothing was found, the search expanded in an effort to find news articles regarding the company and heat storages.

The information found regarding the companies was insufficient in most cases and they were therefor contacted regarding heat storages in their systems. A reference list from the biggest manufacturer of accumulators in Sweden (Rodoverken), as well as two other lists, was available for cross-referencing in case some of the companies did not answer. However most of the data for existing heat storages was acquired through the company's websites or through direct contact with the companies. (Rodoverken, 2013) (Nordvärme, 1993) (Lindberg & Breitholtz, 1998) (Svensk Fjärrvärme, 2016)

In Denmark it tends to be more common to utilize heat storages in smaller district heating systems, as shown in the review article *Thermal energy storage systems for district heating and cooling* by Sven Werner and Henrik Gadd. In this article they investigate the distribution of heat storages in all Nordic countries, though most of the systems analysed are located in Denmark. It will be interesting to see if this also is the case for Swedish district heating systems when a much larger sample is analysed. (Werner & Gadd, 2015)

3.2 System sizes

In order to determine if the installed capacity of heat storages varies depending on the size of the system, data regarding the annual sales of each system was obtained from the Swedish district heating association. The heat storages also had to be matched with the correct district heating system after they had been identified. This data indicates that the 167 of the largest systems are responsible for 97% of the delivered district heating in the country. These are the systems that have been investigated for heat storages in this analysis. Information has not been found for all of the bigger systems, but it has been found for most of them. Though they have not been the main focus of this investigation, information regarding the some of the smaller systems has been found. The data found about these smaller systems has been included in this analysis in order to make it as complete as possible.

The annual heat sales of the systems have been used in order to determine the size of each system analysed. Data from the Swedish District Heating Association has mainly been used for this, but in for some systems there has been no data available regarding this. In these cases the data from the Swedish Energy Market Inspectorate have been used to acquire the systems heat sales. When the verified heat storages all had been matched with their corresponding systems, a diagram was made where the relative storage capacity of the system (m^3/TJ) is compared with the annual heat sales of the system (PJ). With this diagram it is then possible to see the installed storage capacity tends to be higher in small systems or vice versa. The systems that has no installed have their storage capacity set to 0 m^3.

Some of the analysed systems have been combined because it has not been possible to distinguish all systems. This affects the results by reducing the number of district heating systems, giving the affected systems much higher annual heat sales, giving storage capacity to some systems that have none and combining the energy sources and operational costs of the affected systems. This only accounts for a small proportion of the analysed systems though. In one instance, for the systems in Aneby, the data for supplied energy was incorrect. The data for heat sales in the systems were however much more reliable. It was also known that the system only used biofuel for heat generation, thus a plant efficiency ratio of 90% was assumed in order to estimate the heat supply. (Energimarknadsinspektionen, 2016) (Svensk Fjärrvärme, 2016)

3.3 Energy sources

In order to determine if the installed capacity of heat storages varies depending on the energy source that is used in the system, data regarding the supplied energy was ascertained through the Swedish district heating association. The diagram below shows the distribution of energy sources for all the members of the association, which represents approximately 98% of all district heating systems in Sweden.

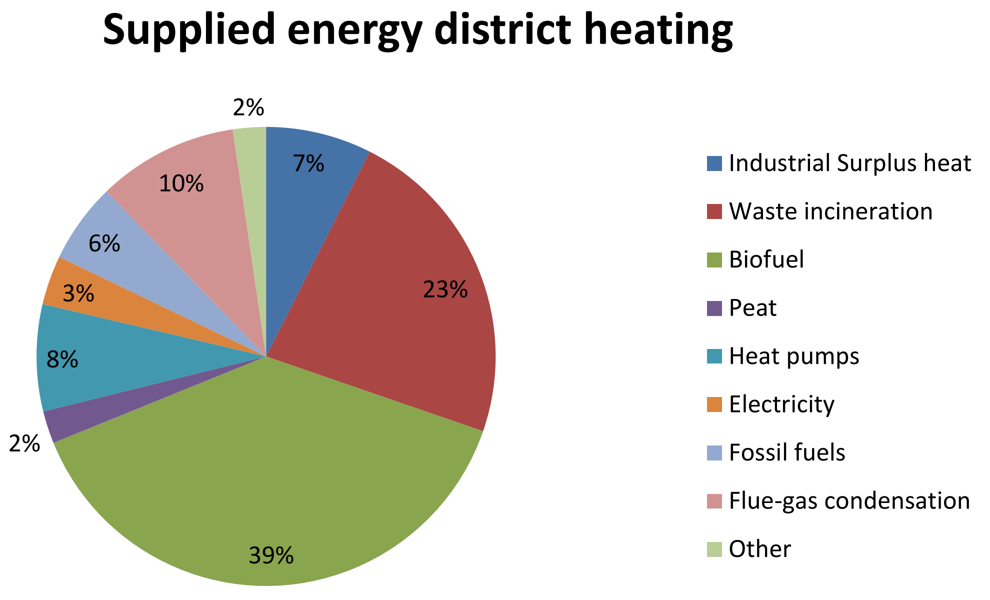

Diagram 2 - Distribution of energy sources for the supplied energy in Swedish district heating systems during 2014. Source: Swedish District Heating Association

As shown in *Diagram 2*, biofuel, waste incineration and industrial surplus heat represents 69% of all energy supplied to district heating systems in Sweden during 2014. These three energy sources are used as references when comparing the different systems, meaning that the relative proportions from those sources of energy are compared to the relative installed storage capacity for each system.

Flue-gas condensation represents 10% of the total heat supply, which makes it the third largest source of heat supply in Sweden during 2014. It is only topped by biofuel and waste incineration. However flue-gas condensation is a method of extracting additional heat from the flue-gas which is leftover from another heat or electrical generating process. This is most commonly used in CHP-plants, which will be the fourth and final energy source used for comparison in the analysis. Although CHP-plants are a technology used for heat generation, rather than a source of energy. Many different sources of energy can therefore be utilized in CHP-plants. It is a very common type of power plant in Sweden, and is therefore included in the comparison. Unfortunately there is no data available about the supplied energy from CHP-plants through the Swedish District Heating Association. Hence another source of data needed to be used. The Swedish Energy Market Inspectorate has data available regarding this, thus their data was used for the heat supply from CHP-plants.

The data for all four energy sources was used to make diagrams where the relative proportions of energy for each source was compared with the installed heat storage capacity for each system. From these diagrams it was then possible to determine whether or not there are any correlations between the installed capacity and the different energy sources. (Energimarknadsinspektionen, 2016) (Svensk Fjärrvärme, 2016)

3.4 Customer prices

To be able to investigate if the installed storage capacity has any influence over the customer prices in the system, information regarding the annual revenues of the systems was needed. This data is available through the Swedish Energy Market Inspectorate, where the annual revenues of each system are listed. The annual heat sales are listed here as well, and thus the customer prices of the system can be obtained by dividing the two. These annual sales does however deviate slightly when compared to the annul sales from the data of the Swedish District Heating Association.

The pricing areas from the Swedish Energy Market Inspectorate are sometimes divided differently than the systems from Swedish District Heating Association, making it difficult to cross-reference some of the systems between the two data bases. When the naming of the price area and the system were too different for cross-referencing, the annual sales of the systems was used to help identify the correct price area for the system. However since annual sales in the two data bases do not always correspond, this was not always possible. Some systems with same company were therefore combined, as mentioned earlier. This allowed data regarding annual revenues for the systems that otherwise would have none regarding this, and this was only done for a very small proportion of the analysed systems.

In the case of two systems, the district heating systems of Ljungby and Södertälje, there was no data available regarding the systems annual revenues of 2014. The latest data available for the system in Södertälje was from 2010, this data was used for this system due to lack of more recent data. There was no data at all regarding the annual revenues of the system in Ljungby in the data from the Swedish Energy Market Inspectorate. The company’s annual report from

2013 was therefore used to obtain information regarding the annual revenues. Net sales for the distribution and generation of district heating were obtained from this report, and then used as the annual revenues of the system. After the customer prices of each system were identified a diagram was made where it is compared to the relative storage capacity of the system. Through this diagram it is then possible to see if the heat storage has any effect on the system's customer prices. All data regarding the district heating systems annual revenues includes VAT. (Energimarknadsinspektionen, 2016) (Ljungby Energi, 2014)

3.5 Maintenance and operational costs

Information regarding the systems operational costs needed to be acquired in order to investigate the influence heat storages have on this aspect of the system. Data regarding these costs was also obtained through the Swedish Energy Market Inspectorate. This data does however also contain the maintenance and fuel costs of the systems, and it was not possible to separate the different costs. The total cost was therefore used for the analysis, which may influence the results. The cost was then divided with the annual heat sales of the corresponding system in order to get the relative operational cost of each system. A diagram was made to compare this with the relative storage capacity of the systems. It is then possible to tell how the storage capacity of the systems influences their maintenance and operational costs through this diagram. All data regarding the district heating systems maintenance and operational costs includes VAT. (Energimarknadsinspektionen, 2016)

4 RESULTS

In this chapter the results of the analysis are presented and analysed. The results are also discussed and compared to existing knowledge in order to get a better understanding of them.

4.1 Existing heat storages

There is a volume of 899 770 m^3 available for heat storage in the examined district heating systems. A total of 167 systems have been analysed, and these systems represents 97% of the annual heat sales in Swedish district heating systems. The size of the heat storages vary from the largest with a storage capacity of 100 000 m^3, to the smallest with a storage capacity of only 50 m^3. Out of the 167 analysed systems, 104 have installed storage capacity. This represents 77% of the annual heat sales, which indicates that most of the delivered district heating in Sweden utilizes heat storages.

Although most of the supplied district heating in Sweden has been investigated, there are still a lot of small systems that are not included in this analysis. There are over 400 district heating systems in Sweden and only 167 of them have been part of the analysis, meaning that there are a lot of smaller systems which could potentially have installed storage capacity. This is likely since heat storages are more commonly used in smaller systems in Denmark. It is also common to generate heat with biomass boilers in smaller systems, which benefits greatly from being able to store heat. If these smaller systems were to be included in the analysis it could drastically alter the results regarding the distribution of storage capacity according to the size of the systems. However, these systems are so small compared to the investigated systems that the total storage volume would not be affected in a significant manner.

In the following tables all analysed systems are listed in regards to their distribution of energy sources, storage capacity and heat sales.

Table 1 - The number of district heating systems with and without storage capacity according to the analyzed energy sources, as well as the distribution of storage capacity for each energy source.

System quantity	With storage	Without storage	Total	Storage volume [m^3]
Systems	104	63	167	899 770
CHP	49	8	57	592 650
Biofuel	97	56	153	896 270
Waste incineration	29	3	32	432 950
Industrial surplus heat	32	10	42	381 570

The total number of investigated district heating systems is listed in *Table 1*, as well as the total storage capacity found in these systems. The table also shows how the storage capacity is distributed in the systems regarding the different energy sources used in the systems. As shown in *Table 1*, district heating systems using biofuel are the systems with access to most of the installed storage capacity. In fact, almost all systems utilize biofuel to some degree and have therefore access to almost all installed storage capacity. Systems that make use of industrial surplus heat have access to the least amount of storage capacity.

Table 2 - The distribution of heat sales in the systems with and without storage capacity according to the analyzed energy sources, as well as the weighted and arithmetic average relative storage capacity for each energy source.

Heat sales	With storage [PJ]	Without storage [PJ]	Total [PJ]	Arithmetic average [m^3/TJ]	Weighted average [m^3/TJ]
Systems	128	34	162	5,6	7,0
CHP	105	16	121	4,9	5,7
Biofuel	127	26	154	5,8	7,1
Waste incineration	87	13	100	4,3	5,0
Industrial surplus heat	76	15	91	4,2	5,0

In *Table 2*, the same distribution is shown. However instead of listing the distribution in terms of system quantity, it shows the systems distribution of heat sales for the systems according to the different energy sources used. The annual heat sales of all analysed systems are equal to 162 PJ, and the heat sales of systems with installed storage capacity represents 128 PJ. The weighted and arithmetic average relative storage capacity for the different energy sources is also listed in *Table 2*. The weighted average shows the average relative storage capacity of the systems with installed storage capacity, which equals 7 m^3/TJ for all analysed systems. The arithmetic average also includes the systems with no storage capacity, which gives an average relative storage capacity of 5.6 m^3/TJ for all analysed systems.

4.2 System sizes

The annual heat sales of the analysed systems vary from 9.5 TJ to 27 PJ, giving a very spread variety of system sizes. Out of these district heating systems, the average annual heat sales are greater for the systems with installed heat storage capacity than the systems with no storage capacity. The average annual heat is 1.3 PJ for the systems with heat storages and 0.5 PJ for the ones without. This indicates that it is more common to utilize heat storages in larger systems in Sweden.

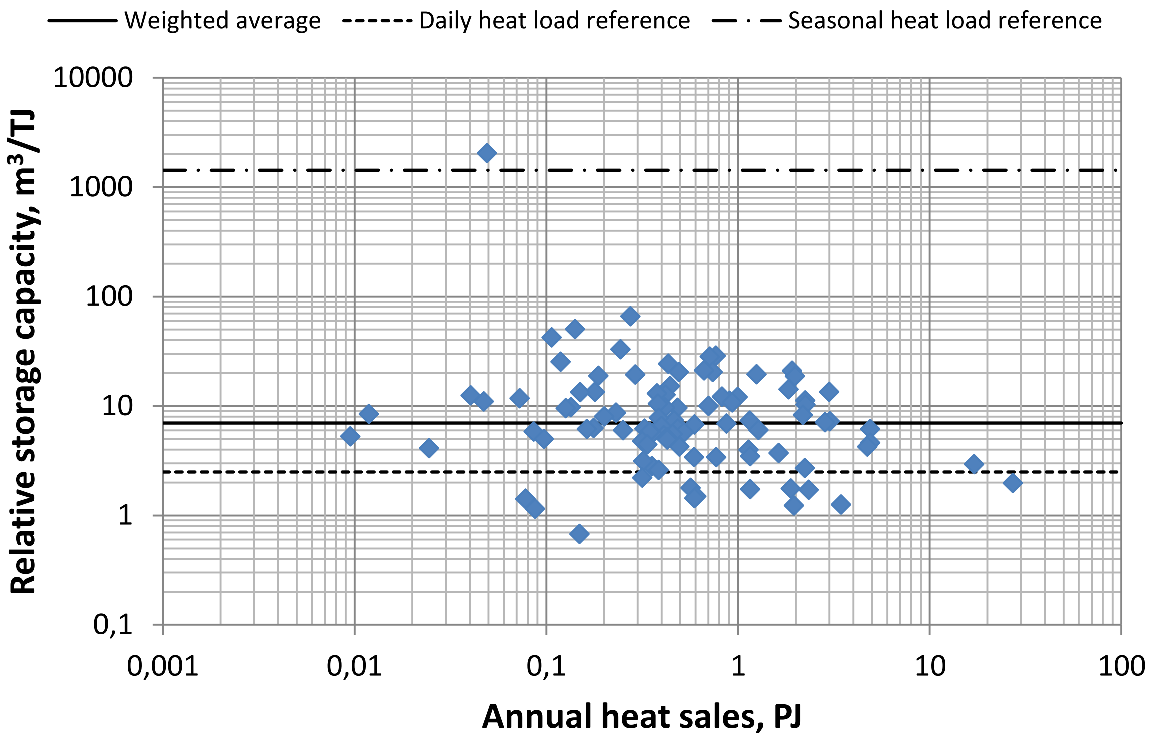

Diagram 3 - The relative storage capacity for each system with installed heat storages, compared to the systems annual heat sales.

By dividing the total installed water volume of the heat storages for a district heating system with its corresponding systems annual heat sales, those systems relative storage capacity can be obtained. As shown in *Diagram 3*, the relative storage capacity has a wide variation from approximately 1 to 70 TJ per m^3 of the heat sales, with a weighted average of 7 m^3/TJ. This wide variation reveals that the heat storages among the analysed system have different design aims. One of the district heating systems, the system in Storvreta, has a much higher storage capacity compared to the rest of the systems. This is because it has the only seasonal heat storage in Sweden, resulting in a very high relative storage capacity of 2035 m^3/TJ. It is a test facility that was designed to store solar heat from the summer to the winter.

There are three reference lines included in *Diagram 3* which represents the daily and seasonal heat load references mentioned in *Section 2.2* of the thesis, as well as the weighted average relative storage capacity of the analysed systems. Most of the heat storages appear to be designed in order to counteract daily heat load variations since the relative storage capacity of most systems exceeds the daily heat load reference. The bottom reference line represents this relative storage capacity needed in order to handle daily heat load variations, which represents 2.5 m^3/TJ. The reference line in the middle represents the weighted average relative storage capacity of the systems and the top reference line represents the relative storage capacity need in order to handle seasonal heat load variations. In order to counteract seasonal heat load variations a relative storage capacity of 1430 m^3/TJ is required. There is only one system with a storage capacity capable of this and that is the system in Storvreta.

4.3 Energy sources

4.3.1 CHP

Heat generated in CHP plants represents 38% of the total heat supply in all investigated district heating systems. CHP plants can utilize various types of fuels; in Sweden biofuel and waste are the two fuels most commonly used in CHP plants. Approximately 35% of all analyzed system generates heat in CHP plants to some degree. The distribution of relative heat storage capacity according to the proportion of heat generated by CHP plants in the analysed systems is depicted in *Diagram 4* and *Diagram 5*. The data regarding heat supply from CHP plants is somewhat incomplete for some systems, which affects the results. This is only an issue for a very small proportion of the analyzed systems though.

As shown in *Diagram 4*, the storage capacity of district heating systems with CHP plants is very spread when compared to the proportion of heat generated in these plants. No trend in regards to the proportion of CHP utilized by the systems can be found because of this wide spread. There is also a wide variety in the relative storage capacity when it is compared for all systems that utilize CHP for heat generation. The relative storage capacity varies from 1 to 42 TJ/m^3. This means that the heat storages in systems with CHP plants also have different design aims, even though they have the same type of energy source. This is not unexpected because all systems have their own heat loads to balance out. Some systems may want to use heat storage in order to replace their peak load boilers, while other systems just wants more flexibility between heat and electric generation. Another reason for the wide spread of relative storage capacity could simply CHP plants ability to use different fuel types.

According to *Diagram 5*, almost all district heating systems that generate heat through CHP plants have installed heat storage capacity. The systems with installed storage capacity represent 86% of all systems that have CHP plants, and only 8 of the systems have no storage capacity installed. This was to be expected since CHP plants gain many advantages with heat storages, such as more flexibility between heat and electric generation. Most district heating systems with CHP plants were therefore expected to have some storage capacity, which also seems to be the case for the analyzed systems.

Diagram 5 also shows that most of the systems with no storage capacity have a high proportion of heat generated in CHP plants. This is not unexpected since the CHP plant is designed to handle most of the daily heat load variations if it generates over 80% of the systems heat supply. The proportion of daily heat load variations that would benefit from installing storage capacity is therefore too small in order to justify the investment. The boilers in these plants may however be oversized, and would rather benefit from having smaller boilers with heat storages to compensate. These systems does have potential for expanding in the future though, as the additional heat demands and heat load variations can be compensated for by installing heat storage capacity.

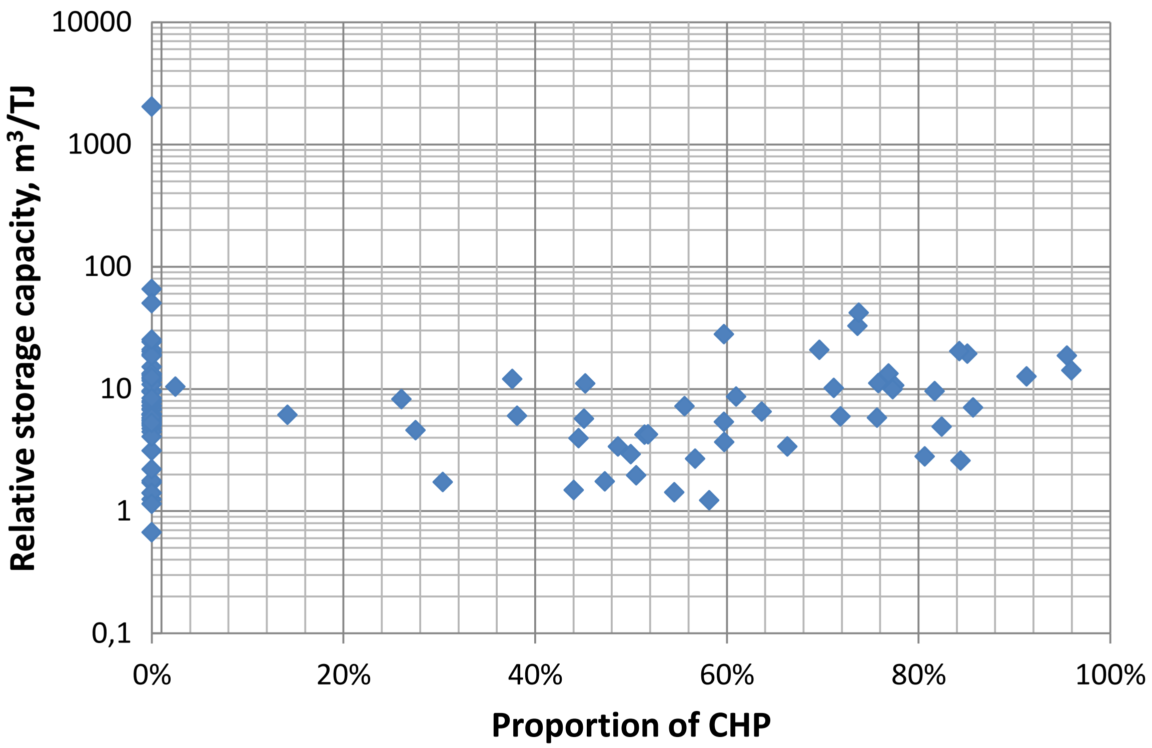

Diagram 4 - The relative storage capacity for all analyzed systems with installed storage capacity, compared with their proportion of heat generated in CHP plants.

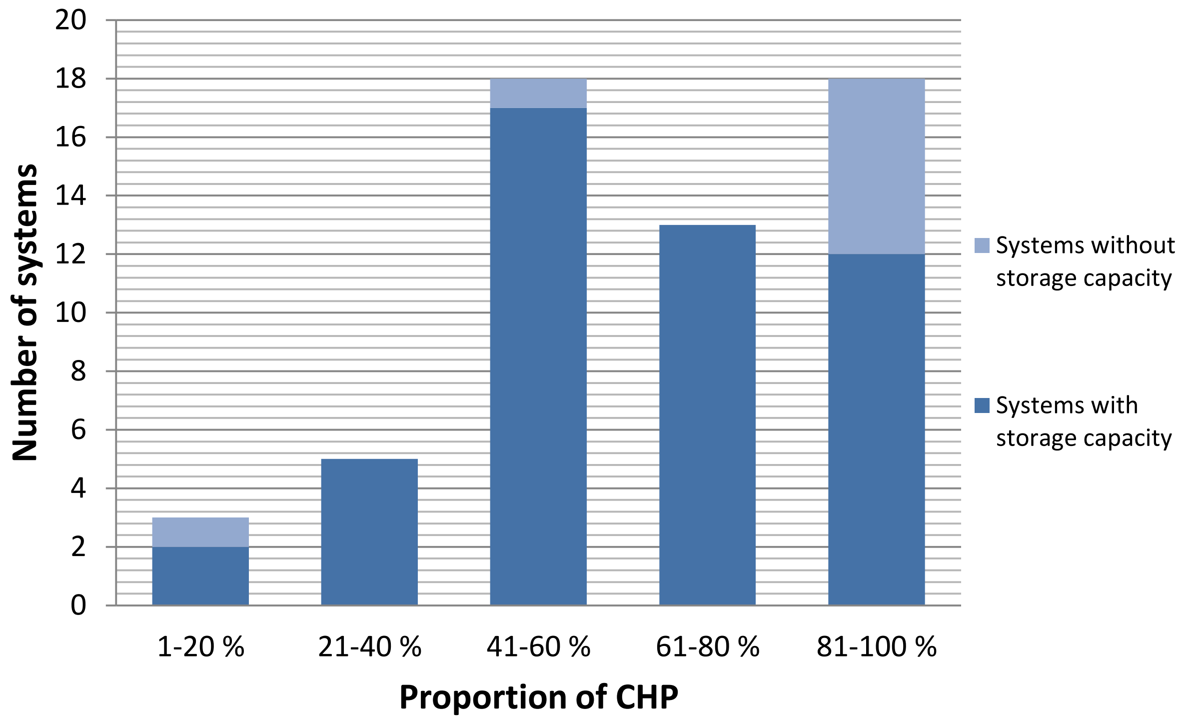

Diagram 5 - The number of analyzed systems that utilizes CHP plants for heat generation are compared in order to investigate the proportion that have installed heat storage capacity.

4.3.2 Biofuel

Heat generated from biofuel represents 33% of the total heat supply in all the investigated district heating systems, and approximately 94% of all investigated systems use biofuel to some extent. The distribution of relative heat storage capacity according to the proportion of heat generated by biofuel in the analysed systems is depicted in *Diagram 6* and *Diagram 7*.

As shown in *Diagram 6*, almost all of the investigated district heating systems utilize biofuel as an energy source. The proportion of biofuel used is however widely spread in the different systems. There is also a large variety in relative storage capacity when it is compared for all systems that utilize biofuel as an energy source. Due to the fact that most systems use biofuel to some extent and that the relative storage capacity varies greatly for all systems, this was to be expected. The relative storage capacity varies from 1 to 65 TJ/m^3 for systems that generate heat using biofuel, excluding the system in Storvreta which have a capacity of 2035 TJ/m^3. This means that the design goals for heat storages in systems that utilize biofuel vary as well.

Many of the systems with storage capacity uses biofuel to generate heat, but a lot of the systems without any storage capacity also utilize biofuel. The systems with installed storage capacity represents 63% of all district heating systems that, to varying degrees, generate heat using biofuel. This is unexpected since a biomass boiler functions better with a constant load, which heat storage helps provide. Hence, most of the systems with biomass boilers were expected to have installed storage capacity. This is not the case according to *Diagram 7*. Most of the systems that do not have any installed storage capacity utilize a high proportion of biofuel. This is however not unexpected. Just like the systems with CHP plants, the biomass boilers are designed to handle most of the daily heat load variations if it generates over 80% of the systems heat supply. Investing in heat storage capacity is therefore hard to justify here as well, because of the small proportion of daily heat load variations that would benefit this. These biomass boilers may also be oversized, and would rather benefit from having smaller boilers with heat storages to compensate. These systems do however have potential for expanding in the future because of this, as the additional heat demands and heat load variations can be compensated for by installing heat storage capacity.

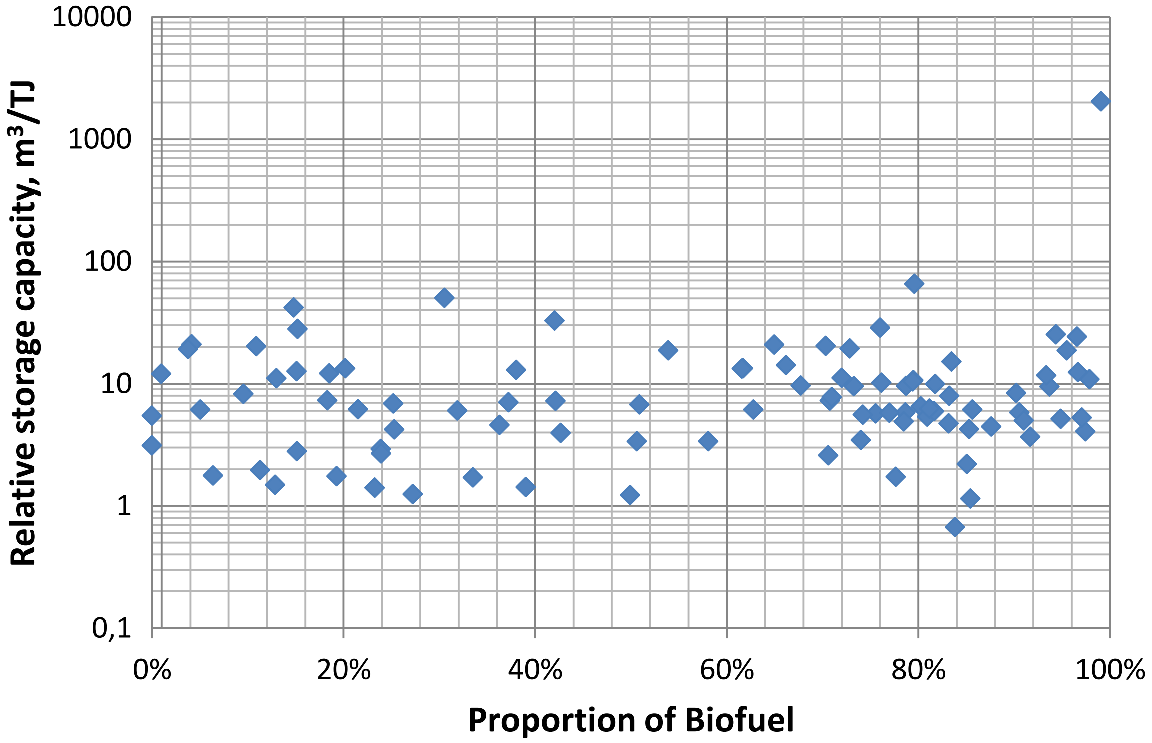

Diagram 6 - The relative storage capacity for all analyzed systems with installed storage capacity, compared with their proportion of heat generated from biofuel.

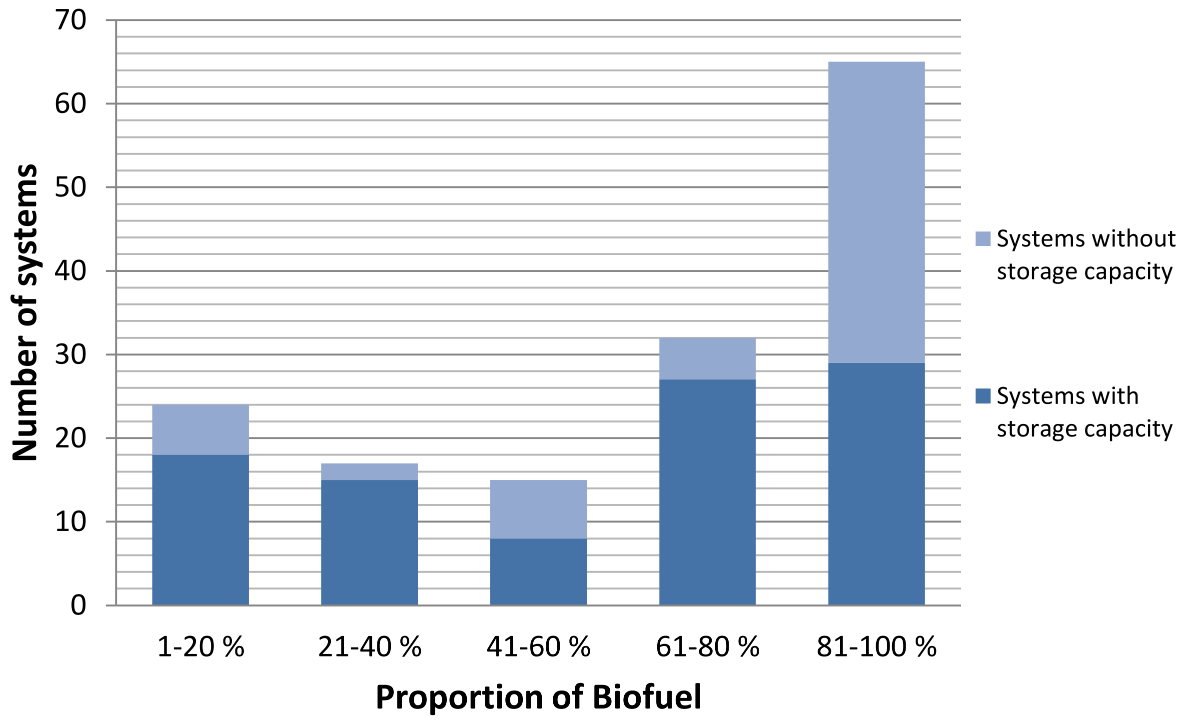

Diagram 7 - The number of analyzed systems that utilizes biofuel for heat generation are compared in order to investigate the proportion that have installed heat storage capacity.

4.3.3 Waste incineration

Waste incineration represents 21% of the total heat supply in the investigated district heating systems, and approximately 20% of all analysed systems use waste incineration to some extent. The distribution of relative heat storage capacity according to the proportion of heat generated by waste incineration in the analysed systems is depicted in *Diagram 8* and *Diagram 9*.

According to *Diagram 8*, the district heating systems with installed storage capacity have a very wide spread in the proportion of waste incineration they utilize for heat generation. The relative storage capacity of these systems is also widely spread, as it varies from 1 to 28 TJ/m^3. However, this gives waste incineration the smallest spread in relative storage capacity out of all the investigated energy sources. This indicates that the design goals of heat storages in district heating systems which utilizes waste incineration does not vary as much as they do for systems which utilizes other energy sources. The design goals still seem to vary though. No further correlations can be found in these regards due to the wide spread of the data.

As shown in *Diagram 9*, most of the systems that generate heat through waste incineration have installed storage capacity, which translates to 91% of the systems. Only three of these systems have no storage capacity. This high proportion of systems with installed storage capacity is very similar to the systems that generate heat in CHP plants, which also have heat storage in a high proportion of the systems. Since waste is often incinerated in CHP plants, this was to be expected.

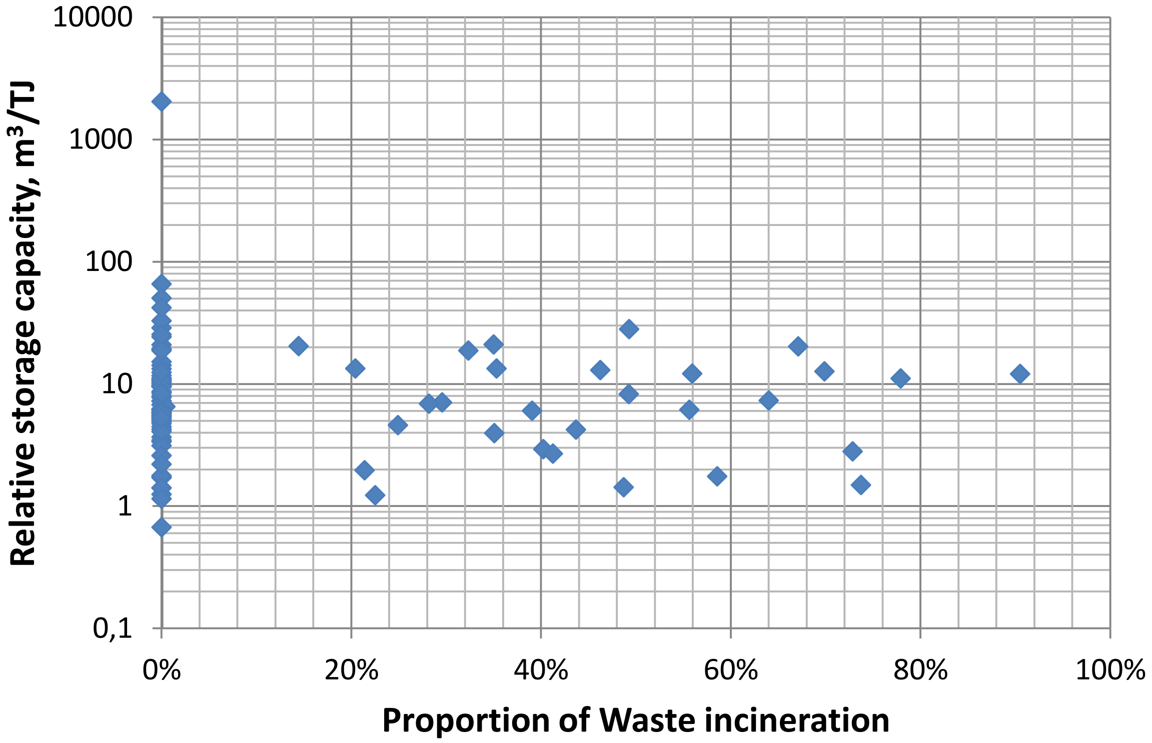

Diagram 8 - The relative storage capacity for all analyzed systems with installed storage capacity, compared with their proportion of heat generated by waste incineration.

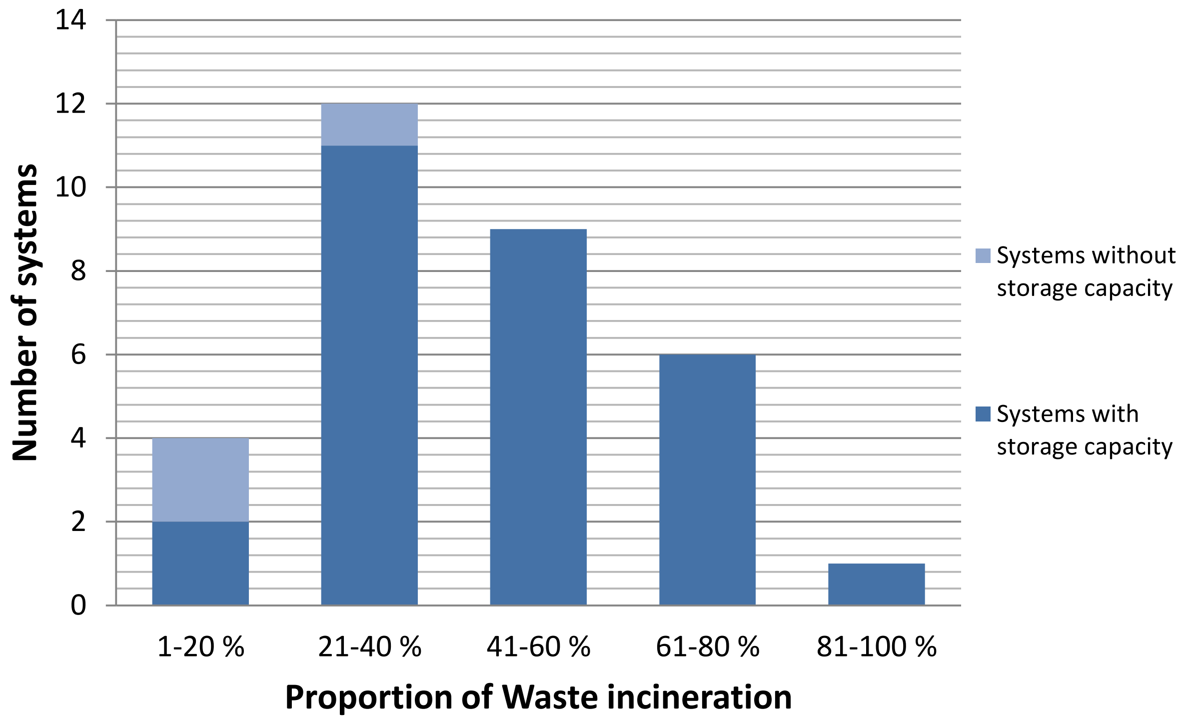

Diagram 9 - The number of analyzed systems that utilizes waste incineration for heat generation are compared in order to investigate the proportion that have installed heat storage capacity.

4.3.4 Industrial surplus heat

Industrial surplus heat represents 7% the total heat supply in the investigated district heating systems, and approximately 26% of all analysed systems use industrial surplus heat to some extent. The distribution of relative heat storage capacity according to the proportion of industrial surplus heat in the analysed systems is depicted in *Diagram 10* and *Diagram 11*.

There are not a lot of district heating systems that makes use of industrial surplus heat, as can be seen in *Diagram 10* and *Diagram 11*. This is a bit unexpected since industrial surplus heat is an ideal energy source for district heating systems. Most of the systems that do utilize industrial surplus heat have installed storage capacity, which translates to 76% of the systems. This was to be expected because heat storages make the acquisition of surplus easier by allowing the surplus energy to be stored until it is needed. Since it is likely that the industry generates the surplus heat during the day when the heat demand is low for space heating, it will not always be advantageous to supply it directly into the system.

As shown in Diagram 10, the district heating systems with installed storage capacity have a very wide spread in the proportion of industrial surplus heat they utilize. The relative storage capacity of these systems is also widely spread, as it varies from 1 to 50 TJ/m^3. No correlations can be found in these regards, other than the fact that the heat storages in these systems have different design aims, because of these wide spreads of data.

According to *Diagram 11*, heat storages are used more often in systems where industrial surplus heat represents a smaller proportion of the heat supply. This makes sense because if surplus heat from an industrial process represents the majority of the heat supply, then it is probably a continuous process that is capable of constantly supplying heat to the district heating system. Heat storages are therefore made obsolete in those systems.

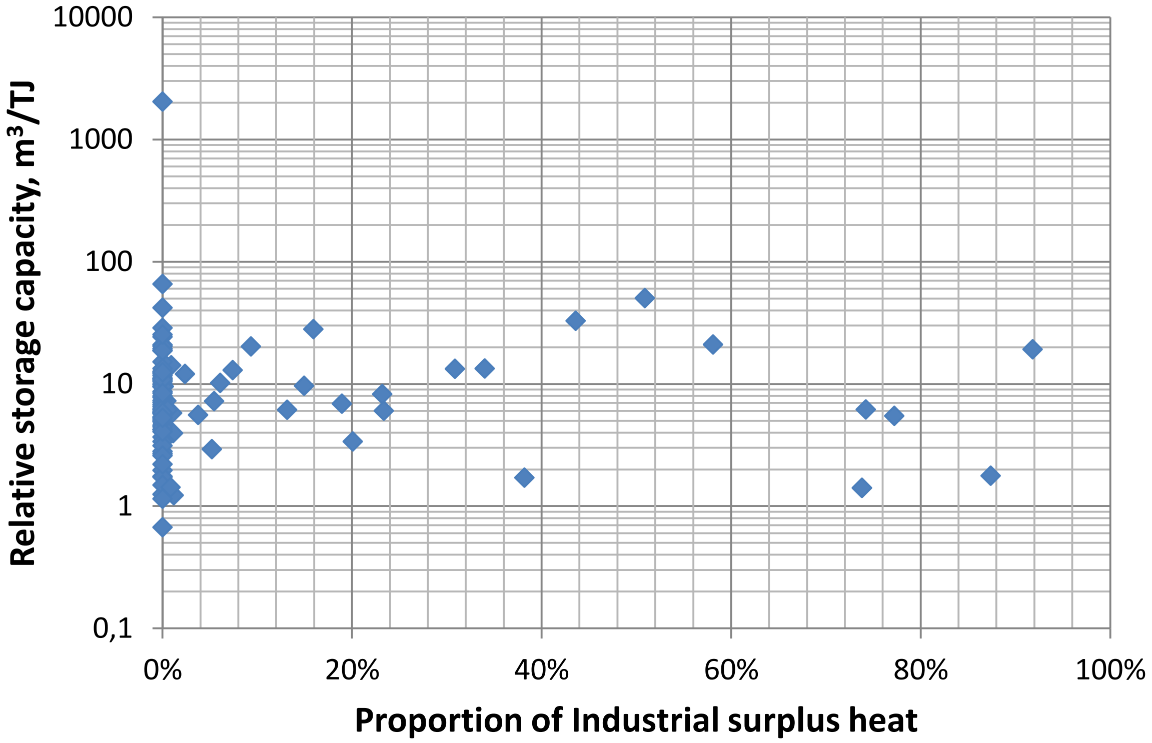

Diagram 10 - The relative storage capacity for all analyzed systems with installed storage capacity, compared with their proportion of heat generated from industrial surplus heat.

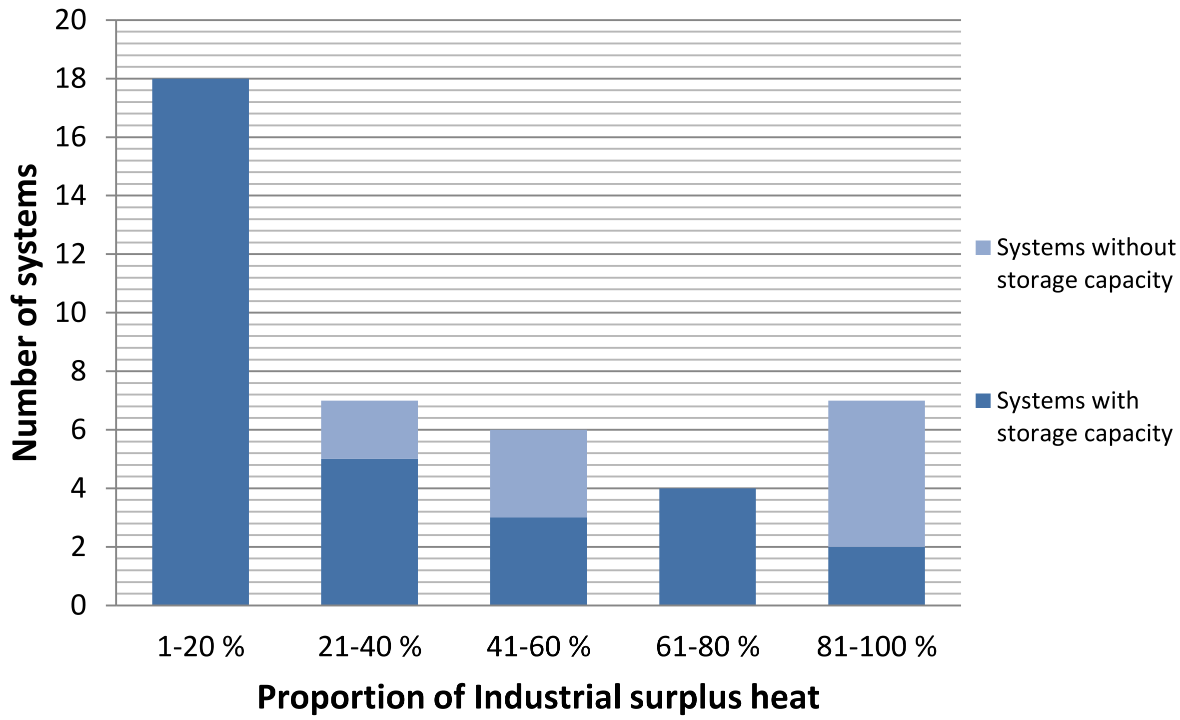

Diagram 11 - The number of analyzed systems that utilizes industrial surplus heat are compared in order to investigate the proportion that have installed heat storage capacity.

4.4 Customer prices

The customer prices of each system have been determined by dividing the systems annual revenues with their annual heat sales, thus giving the district heating systems average annual revenues. No significant difference in average annual revenues between systems with or without installed storage capacity can be found for the investigated systems. The average annual revenues for systems with installed storage capacity are 664 kr/MWh, while the average annual revenues for systems with no storage capacity are 674 kr/MWh. This indicates that there is only a 1% difference in the prices of district heating in depending on the systems storage capacity, which a too small of a difference in order to draw any conclusions.

The prices of district heating in systems with installed storage capacity were expected to be lower due the fact that operational costs also were expected to be lower with available heat storage capacity, thus allowing more competitive prices. This does however not appear to be the case for the analysed district heating systems. The most possible explanation for this is that the money saved from lowered operational costs is reinvested in the heat storages, thus eliminating the need to raise customer prices. It should also be noted that the district heating companies all have their own price modules which they base their prices upon, which is a factor that influences the results.

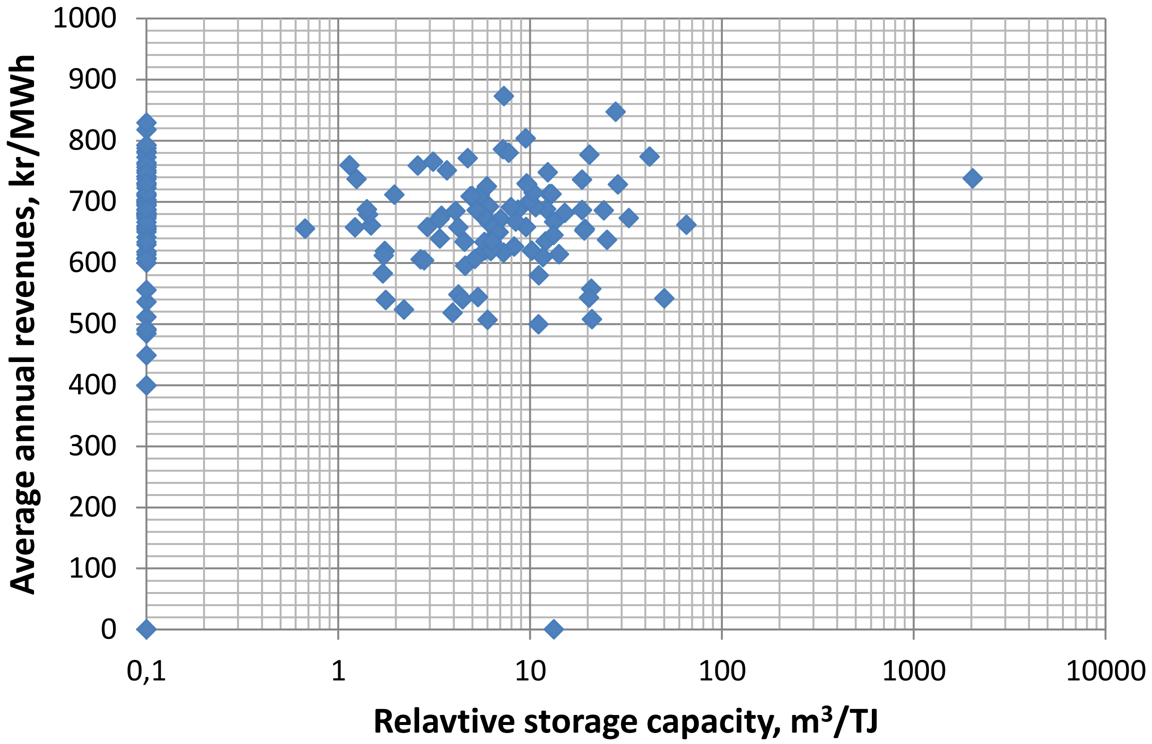

Diagram 12 - The annual revenues divided by the annual heat sales for each system investigated, compared to the corresponding systems relative storage capacity.

As depicted in *Diagram 12*, no pattern can be found for the distribution of relative storage capacity when compared to the average annual revenues. The higher the relative storage capacity, the more load variations and peaks can be balanced out without the need to utilize peak and backup plants. This in turn leads to reduced fuel and operational costs, which should allow more competitive prices for systems with higher relative storage capacity. There is however no indication of this in *Diagram 12*. The diagram shows a very wide spread of the average annual revenues in relation to the relative storage capacity of the systems, meaning that no correlation can be found between these two parameters.

4.5 Maintenance and operational costs

The average annual costs for systems with installed storage capacity are 374 kr/MWh and the costs are for 399 kr/MWh systems without storage capacity. This means that the operational costs for systems with installed storage capacity are 6% lower, which is expected due to the fact that heat storages allows the systems to operate more efficiently. This is a significant difference which concludes that heat storages lower a district heating systems operational costs. The money saved by installing heat storage capacity can then be used in order to help funding the heat storage. *Diagram 13* depicts the distribution of the average annual operational costs for all analysed systems compared to the systems relative storage capacity.

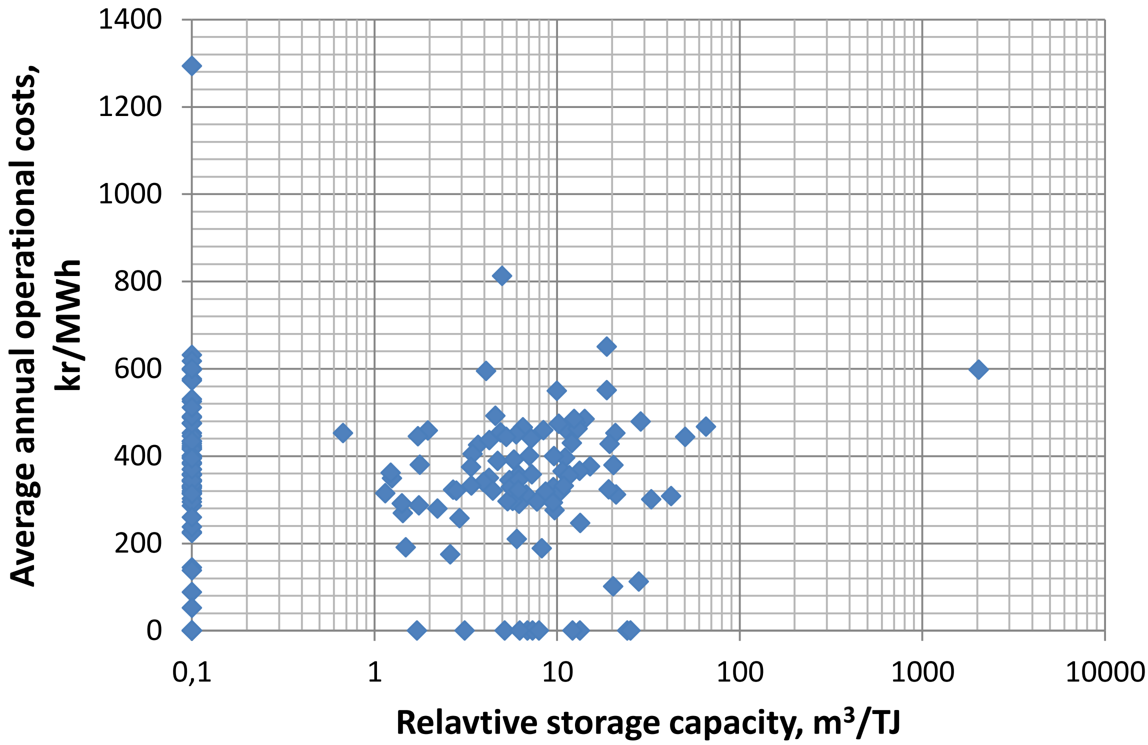

Diagram 13 - The annual operational costs divided by the annual heat sales for each system, compared to the corresponding systems relative storage capacity.

As shown in *Diagram 13*, the distribution of average annual operational costs compared to the systems relative storage capacity is spread very widely. No correlations between the relative storage capacity and the systems operational costs can therefore be found. With higher relative storage capacity more of the heat loads in the system can be balanced out, thus allowing the system to operate more efficient and reduce the amount of fuel needed in order to compensate for load spikes. The operational costs of the systems were therefore expected to decrease with higher relative storage capacity, but this does not appear to be the case for the analysed district heating systems.

5 CONCLUSIONS AND FUTURE WORK

In this chapter the conclusions that can be drawn from the results are presented. The conclusions will try to answer the scientific questions which from the purpose of this thesis. Suggestions regarding future work in the subject is also be presented in this chapter.

5.1 Conclusions

Quantification of the installed heat storage capacity in Swedish district heating systems has been the main purpose of this thesis. According to the results of the analysis, most of the systems utilize heat storages to some extent. The design purposes of the installed heat storages seem to differ when analyzing the four scientific questions that help form the purpose of this analysis. These are the conclusions that can be drawn from the results regarding these four questions:

- The distribution of storage capacity is randomly spread throughout the investigated district heating systems. Although the distribution appears to be random, it can be concluded that heat storages is more commonly utilized in larger systems. This is due the average annual heat sales being significantly higher in the district heating with installed storage capacity. No trend in regards to relative storage capacity of the system can be found. Since the relative storage capacity is an indicator of the purpose of the heat storage, it can be concluded that the analyzed systems have many different design aims.
- Through the data presented in the results, it can be concluded that heat storages is more commonly used in district heating systems that generate heat in CHP plants or through waste incineration. These two does however overlap often. In systems that mainly use one energy source for heat generation it is more uncommon with storage capacity then in systems with smaller proportions of multiple energy sources. Thus, it can be concluded that heat storages are utilized more in systems with smaller boilers.
- The results show no significant difference between customer prices in systems with installed storage capacity and customer prices in systems without storage capacity. This leads to the conclusion that heat storages does not allow more competitive prices for district heating, even though the fuel and operational costs may be lowered. The money saved by reducing the operational costs of a district heating system is most likely committed towards the heat storage in an effort to avoid raising the customer prices.
- The annual operational costs of the analyzed systems with installed storage capacity are lower than the costs of the systems with no storage capacity. Therefore it can be concluded that heat storage influences the operational costs of district heating systems by reducing them.

Most of the investigated district heating systems with installed storage capacity have a relative storage capacity that is capable of handling daily heat load variations, and only one of these systems is capable of handling seasonal load variations. It can be concluded that most of the heat storages are intended to counteract daily load variations because of this. The distribution of the identified heat storages does however appear random for all analyzed aspects of the analysis. This means that the design aims of the existing heat storages vary in all of the analyzed systems, regardless of what energy source that is used for heat generation. In turn, this indicates that the systems have daily heat load variations of varying magnitude which they need to deal with.

5.2 Future work

The possibility of storing thermal energy is crucial in order to use generated heat or electricity as efficiently as possible, as well as being able to integrate as much renewable energy sources as possible into the energy systems. All data gathered regarding the existing storage capacity in district heating systems will therefore be very useful in future research that expands upon the idea of utilizing heat storages in any manner. The electrical grid is in need of a balancing power which the investigated heat storages can help to provide. Calculating the feasibility of using heat storages as a balancing power for the electrical grid is a potential future study which would utilize the data gathered in this thesis. Future planning of wind power plants and solar power plants can also benefit from such studies. This is due to power generation of these types of plants being dependent on the weather, which can cause problems for the power balance of the electrical grid. If the planning of such power plants is able to take heat storages into account for the purpose of power balancing, it can aid the motivation of investing in these renewable energy sources. A study investigating the impact of using heat storages as a balancing power for renewable energy sources can therefore prove very insightful.

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APPENDIX A: CONTACTED COMPANIES

Alingsås Energi Nät AB; email contact

Alvesta Energi AB; email contact

Aneby Miljö & Vatten AB; email contact

Arvika Fjärrvärme AB; email contact

Bollnäs Energi AB; email contact

Borgholm Energi AB; email contact

Bromölla Fjärrvärme AB; email contact

E.ON Värme Sverige AB; email contact

Eksjö Energi AB; email contact

Emmaboda Energi & Miljö AB; email contact

ENA Energi AB; email contact

Falbygdens Energi AB; email contact

Falu Energi & Vatten AB; email contact

Finspångs Tekniska Verk AB; email contact

Fortum Värme AB; phone contact

Gislaved Energi AB; email contact

Gotlands Energi AB; email contact

Gällivare Energi AB; email contact

Göteborg Energi AB; email contact

Götene Vatten & Värme AB; email contact

Habo Energi AB; email contact

Hagfors Energi AB; email contact

Halmstads Energi & Miljö AB; email contact

Härnösand Energi & Miljö AB; email contact

Hässleholm Miljö AB; email contact

Höganäs Energi AB; email contact

Jokkmokks Värmeverk AB; email contact

Jönköping Energi AB; email contact

Kalmar Energi Värme AB; email contact

Karlshamn Energi AB; email contact

Karlstads Energi AB; email contact

Kils Energi AB; email contact

Kristinehamns Fjärrvärme AB; email contact

Kungälv Energi AB; email contact

Köpings kommun; email contact

Lantmännen Agrovärme AB; email contact

Laxå Värme AB; email contact

Lerum Fjärrvärme AB; email contact

LEVA i Lysekil AB; email contact

Ljungby Energi AB; email contact

Luleå Energi AB; email contact

Mjölby-Svartådalen Energi AB; email contact

Mälarenergi AB; email contact

Mölndal Energi AB; email contact

Nybro Energi AB; email contact

Nässjö Affärsverk AB; email contact

Oskarshamn Energi AB; email contact

Oxelö Energi AB; email contact

Pite Energi AB; email contact

Rindi Energi AB; email contact

Ronneby Miljö och Teknik AB; email contact

Rättviks Teknik AB; email contact

Sala-Heby Energi AB; email contact

Skara Energi AB; email contact

Skellefteå Kraft AB; email contact

Sollentuna Energi AB; email contact

Statkraft Värme AB; email contact

Stenungsunds Energi & Miljö AB; email contact

Strängnäs Energi AB, SEVAB; email contact

Sävsjö Energi AB; email contact

Södertörns Fjärrvärme AB; email contact

Tekniska Verken i Linköping AB; email contact

Telge Nät AB; email contact

Tidaholms Energi AB; email contact

Tierps Fjärrvärme AB; email contact

Tranås Energi AB; email contact

Trelleborgs Fjärrvärme AB; email contact

Trollhättan Energi AB; email contact

Ulricehamns Energi AB; email contact

Vara Energi Värme AB; email contact

Vattenfall AB Värme; email contact

Vetlanda Energi och Teknik AB; email contact

Väner Energi AB; email contact

Värmevärden AB; email contact

Västervik Miljö & Energi AB; email contact

Ystad Energi AB; email contact

Ånge Energi AB; email contact

Öresundskraft AB; email contact

Österlens Kraft AB; email contact

APPENDIX B: ANALYZED SYSTEMS

Company	**System**	**Storage volume [m^3]**
Vattenfall AB Värme	Storvreta	100000
Fortum Värme AB	Stockholm totalt	53400
Växjö Energi AB	Växjö	40000
Öresundskraft AB	Helsingborg	40000
Borås Energi och Miljö	Borås	37000
E.ON Värme Sverige AB	Norrköping-Söderköping	36000
Vattenfall AB Värme	Uppsala	30000
Jämtkraft AB	Östersund	26000
Eskilstuna Energi & Miljö AB	Eskilstuna-Torshälla	25000
Kalmar Energi Värme AB	Kalmar	24200
Mälarenergi AB	Västerås	22500
Affärsverken Karlskrona AB	Karlskrona	22000
Kraftringen Energi AB	Eslöv-Lund-Lomma m fl	20000
Tekniska Verken i Kiruna AB	Kiruna C	20000
Tekniska Verken i Linköping AB	Linköping	20000
Umeå Energi AB	Umeå	20000
Sundsvall Energi	Sundsvall	18000
Vimmerby Energi & Miljö AB	Vimmerby	18000
Skellefteå Kraft AB	Skellefteå	15000
Värmevärden AB	Avesta	15000
Köpings kommun	Köping	14000
Lidköpings Värmeverk AB	Lidköping	12000
Nybro Energi AB	Nybro	10500
E.ON Värme Sverige AB	Malmö	10000
Bodens Energi AB	Boden	10000
Strängnäs Energi AB, SEVAB	Strängnäs	10000
Uddevalla Energi AB	Uddevalla	10000
Vattenfall AB Värme	Nyköping	10000
Falu Energi & Vatten AB	Falun	8400
Skellefteå Kraft AB	Lycksele	8000
Värmevärden AB	Hofors(Värmevärden)	8000
Borlänge Energi	Borlänge	7700
Smedjebacken Energi & Vatten AB	Smedjebacken	7100
ENA Energi AB	Enköping	7000
Ystad Energi AB	Ystad	6700
Jönköping Energi AB	Jönköping	6000
Landskrona Energi AB	Landskrona	6000
Vattenfall AB Värme	Drefviken	6000
Linde Energi AB	Lindesberg	5600
Bollnäs Energi AB	Bollnäs	5300
Finspångs Tekniska Verk AB	Finspång	4900

Company	System	Storage volume [m³]
Värnamo Energi AB	Värnamo	4600
Munkfors Energi AB	Munkfors	4500
Skövde Värmeverk AB	Skövde	4500
Norrenergi AB	Sundbyberg-Solna	4300
C4 Energi AB	Kristianstad	4000
Gävle Energi AB	Gävle	4000
Mjölby-Svartådalen Energi AB	Mjölby	4000
Norrtälje Energi AB	Norrtälje	4000
Statkraft Värme AB	Kungsbacka	4000
Ljusdal Energi AB	Ljusdal	3500
Ljungby Energi AB	Ljungby	3400
Halmstads Energi & Miljö AB	Halmstad	3300
Alingsås Energi Nät AB	Alingsås	3000
Nässjö Affärsverk AB	Nässjö	3000
Solör Bioenergi Svenljunga AB	Svenljunga	3000
Varberg Energi AB	Varberg (Fjv)	3000
Vattenfall AB Värme	Motala	3000
Sandviken Energi AB	Sandviken	2600
Vetlanda Energi och Teknik AB	Vetlanda	2600
Vattenfall AB Värme	Vänersborg	2500
Karlstads Energi AB	Karlstad	2400
Tidaholms Energi AB	Tidaholm	2400
Tranås Energi AB	Tranås	2200
Väner Energi AB	Mariestad	2200
Sala-Heby Energi AB	Sala-Heby	2100
Söderhamn Nära AB	Söderhamn	2100
E.ON Värme Sverige AB	Älmhult	2000
Arvika Fjärrvärme AB	Arvika	2000
Härnösand Energi & Miljö AB	Härnösand	2000
Perstorps Fjärrvärme AB	Perstorp	2000
Trollhättan Energi AB	Trollhättan	2000
Västerbergslagens Energi AB	Fagersta	2000
Västerbergslagens Energi AB	Ludvika	2000
Älvsbyns Energi AB	Älvsbyn	2000
E.ON Värme Sverige AB	Hallsberg-Örebro-Kumla	1800
Kraftringen Energi AB	Klippan-Ljungbyhed-Östra Ljungby	1800
Hedemora Energi AB	Hedemora	1600
Arboga Energi AB	Arboga	1500
Mark Kraftvärme AB	Assbergs nätet	1500
Vasa Värme Kalix AB	Kalix	1500
Värmevärden AB	Hällefors	1300
Kils Energi AB	Kil	1200
Hedemora Energi AB	Säter	1100

Company	System	Storage volume [m^3]
Eksjö Energi AB	Eksjö	1000
Hagfors Energi AB	Hagfors	1000
Karlshamn Energi AB	Karlshamn	1000
Kristinehamns Fjärrvärme AB	Kristinehamn	1000
Kungälv Energi AB	Kungälv	1000
Västervik Miljö & Energi AB	Västervik	900
Hässleholm Miljö AB	Hässleholm	850
Väner Energi AB	Töreboda	850
Alvesta Energi AB	Alvesta	700
Eksjö Energi AB	Mariannelund	515
Värmevärden AB	Kopparberg	500
Västervik Miljö & Energi AB	Gamleby	500
Lerum Fjärrvärme AB	Lerum	485
Ånge Energi AB	Ånge	110
Ånge Energi AB	Ånge	110
Borgholm Energi AB	Borgholm	100
Emmaboda Energi & Miljö AB	Emmaboda	100
Vetlanda Energi och Teknik AB	Holsby	100
Ånge Energi AB	Fränsta	100
Eksjö Energi AB	Ingatorp	50
Aneby Miljö & Vatten AB	Aneby	0
Bromölla Fjärrvärme AB	Bromölla	0
Falbygdens Energi AB	Floby	0
Falbygdens Energi AB	Falköping	0
Falbygdens Energi AB	Stenstorp	0
Gislaved Energi AB	Gislaved	0
Gotlands Energi AB	Visby	0
Gällivare Energi AB	Gällivare-Malmberget	0
Göteborg Energi AB	Göteborg totalt	0
Götene Vatten & Värme AB	Götene	0
Habo Energi AB	Habo	0
Höganäs Energi AB	Höganäs	0
Jokkmokks Värmeverk AB	Jokkmokk	0
Jämtkraft AB	Åre	0
Lantmännen Agrovärme AB	Ödeshög	0
Lantmännen Agrovärme AB	Grästorp	0
Lantmännen Agrovärme AB	Kvänum	0
Lantmännen Agrovärme AB	Skurup	0
Laxå Värme AB	Laxå	0
LEVA i Lysekil AB	Lysekil	0
Luleå Energi AB	Råneå	0
Luleå Energi AB	Luleå	0
Mälarenergi AB	Kungsör	0

Company	System	Storage volume [m^3]
Mölndal Energi AB	Mölndal totalt	0
Oskarshamn Energi AB	Oskarshamn	0
Oxelö Energi AB	Oxelösund	0
Pite Energi AB	Piteå	0
Rindi Energi AB	Tomelilla	0
Rindi Energi AB	Sjöbo	0
Rindi Energi AB	Filipstad	0
Rindi Energi AB	Hörby	0
Rindi Energi AB	Flen	0
Rindi Energi AB	Vadstena	0
Ronneby Miljö och Teknik AB	Bräkne-Hoby	0
Ronneby Miljö och Teknik AB	Ronneby-Kallinge	0
Rättviks Teknik AB	Rättvik	0
Skara Energi AB	Skara	0
Sollentuna Energi AB	Sollentuna	0
Statkraft Värme AB	Åmål	0
Statkraft Värme AB	Trosa	0
Stenungsunds Energi & Miljö AB	Stenungsund	0
Sävsjö Energi AB	Sävsjö	0
Södertörns Fjärrvärme AB	Södertörn Fjärrvärme Totalt	0
Tekniska Verken i Linköping AB	Skärblacka	0
Tekniska Verken i Linköping AB	Kisa	0
Tekniska Verken i Linköping AB	Åtvidaberg	0
Tekniska Verken i Linköping AB	Katrineholm	0
Telge Nät AB	Södertälje	0
Tierps Fjärrvärme AB	Örbyhus	0
Tierps Fjärrvärme AB	Tierp	0
Trelleborgs Fjärrvärme AB	Trelleborg Fjärrvärme AB	0
Ulricehamns Energi AB	Ulricehamn	0
Vara Energi Värme AB	Vara	0
Vattenfall AB Värme	Knivsta	0
Vattenfall AB Värme	Askersund	0
Vattenfall AB Värme	Gustavsberg	0
Vattenfall AB Värme	Haparanda	0
Vattenfall AB Värme	Saltsjöbaden	0
Värmevärden AB	Nynäshamn	0
Värmevärden AB	Hudiksvall	0
Öresundskraft AB	Ängelholm	0
Österlens Kraft AB	Simrishamn	0
Övik Energi AB	Örnsköldsvik	0

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